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19. Abstract (continued)

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FIORD TO DEEP-SEA SEDIMENT TRANSFERS ALONG THE NORTHEASTERN CANADIAN CONTINENTAL MARGIN:MODELS AND DATA

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ABSTRACT

In Alaskan fiords, sedimentation rates are high; during a glacial advance fiord-basin sediments are transported to the ice front to form a shoal which reduces the calving rate. Thus, during successive glacial cycles sediment is initially stored and then removed from fiord basins. In the fiords of eastern Baffin Is. sedimentation rates are, and were, much lower (< 1000 Kg/m2 ka), and fiord-basin fills may span several glacial cycles. This hypothesis is in keeping with the relatively low sedimentation rates on the adjacent shelf (50 to 500 Kg/m2 ka) and deep-sea plain (<=50 Kg/m2 ka). The advance of outlet glaciers through these arctic fiords may be explained by the in situ growth of a floating ice-shelf, grounded at the mouth of the fiord. The extent of late Foxe Glaciation in McBeth and Itirbilung fiords can be delimited by raised marine deltas (50-85 m asl) with ^{14}C dates on in situ shells and whalebone of >54 ka. Holocene raised beaches are lower and date <10 ka. These data, plus the absence of lodgements tills in raised marine sections along the outer coast, make it difficult to extend grounded ice onto the shelf during the 18 ka global maximum. Piston cores from Tingin, Itirbilung and McBeth fiords vary between 4 and 11 m in length, but only sample a proportion of the total basin-fills. Calculations of sediment accumulation rates are not trivial because of problems in the ^{14}C dating of total organics and questions on the true age and sample depth of the tops of the piston cores.

INTRODUCTION

Fiords are deep, narrow arms of the sea that characterize glaciated landscapes (e.g. Syvitski et al., 1987). They are commonly cited as prime examples of the efficiency of glacial erosion (Sugden and John, 1976). During the development of ice sheets over northern Canada (cf. Ives et al., 1975) there would come a time when outlet glaciers would attempt to move seaward through the fiords. However, recent research on tidewater glaciers in Alaska (e.g. Meier and Post, 1987; Brown et al., 1982) indicates that the calving rate increases as a function of water depth. For the glacier to advance the calving rate has to be less than the forward velocity of the ice. In Alaska, observations indicate that during glacier advances fiord-basin sediments are transported to the ice front to form a moraine shoal (Fig. 1) which has the effect of reducing the calving rate. Thus during a glacial cycle, sediment is removed from the fiord; coarse sediments are probably stored along the maximum ice-front limit in the form of moraines and banks, but the finer-grained sediments are deposited on the shelf and in adjacent deep-sea basins.

The Alaskan model (Fig. 1) suggests that there should be distinct pulses in the offshore rate of sediment accumulation that can be associated with fiord-sediment evacuation. Furthermore, it is implicit that fiord basin-fills only span a single glacial cycle. In this scenario (Fig. 1), the ice can continue to erode the basal bedrock once the sediment has been transported to the ice front. Such a process might explain the suggested high rates of glacial

erosion for the eastern sectors of the Laurentide Ice Sheet which were derived from a sediment balance analysis of the northwest North Atlantic (Laine, 1980; Bell and Laine, 1985).

During interglacials and interstadials, that is during periods when glaciation is normally reduced, fiord basins act as major sediment traps in the terrestrial to deep-sea sediment pathway. These nearshore basins hinder the "normal" relationship of sediment transport from rivers onto the continental shelves and to the deep-sea (e.g. Hay and Southam, 197?). However, a major question is the rate and nature of sedimentation in Baffin Bay. The Ocean Drilling Site (ODP) 645 was located at the foot of the slope east of Clyde Fiord (the fiord north of Inugsuin). The cruise report (Srivastava et al., 1987) draws attention to differences in the estimated rates of deep-sea sediment accumulation from around 130 m/my to 6 to 9 times less. Furthermore, the section ODP drilled consisted of sedimentary cycles with an estimated 7.7 ka periodicity; in the "glacial" section these were dominated by detrital carbonates. However, delivery of sediment from an ice sheet on the shelf-break of eastern Baffin Is. should be dominated by non-carbonate source rocks. The carbonate sources are most probably associated with major ice masses which moved toward Baffin Bay through the Arctic Channels (Kravitz, 1982; Klassen, 1985; Andrews et al., 1985b). The dominance of detrital carbonate in the "glacial" units at site 645 itself suggests that the delivery of sediment from Canadian Shield sources was restricted. Why?

The question addressed in this paper is the applicability of the Alaskan scheme (Fig. 1) to an arctic setting, where even

today fast-ice exists for 9-10 months of the year, where the mean annual temperature on land is ca. -12 C, and the water temperatures are frequently below 0 C (cf. Gilbert, 1982, 1983; Syvistki, 1986; Jacobs et al. 1985). Following a discussions of the situation in the Eastern Canadian Arctic and Alaska, field and piston core data are presented from fiords in east-central Baffin Is. (Tingin, Itiribilung, McBeth, and Inugsuin) in an attempt to 1) delimit the late Foxe glacial maximum; 2) define Holocene sedimentation rates; and 3) attempt to delimit the age of the fiord-basin fills.

AN ARCTIC FIORD GLACIER MODEL

As part of the Canadian Sedimentology of Arctic Fiords Experiment (S.A.F.E.) project (Syvitski and Schafer, 1985; Gilbert, 1985) a series of fiords along the eastern margin of Baffin Is. (Fig. 2) were surveyed for bathymetry, sediment thickness, and acoustic facies; piston cores were obtained from one or more basins in ten fiords (Syvitski and Blakeney, 1983; Syvitski, 1984; Syvitski and Praeg, 1987). A critical part of this project was the determination of sedimentation accumulation based on accelerator mass spectrometry (AMS) radiocarbon dates (e.g. Jennings, 1986; Andrews, 1987a; Andrews and Laymon, in press). The problems of evaluating dates from these environments are discussed in Fillon et al. (1981), Mudie and Guilbault (1982), Andrews et al. (1985a, 1986) and Short et al. (subm.).

The gradient in Holocene sediment accumulation from outer fiord basins to the deep-sea is illustrated as Figures 3 and 4. The

rate of sediment accumulation in Baffin Bay and the northern Labrador Sea is currently under debate (De Vernal et al., 1987; Srivastava et al.,1987; cf. Aksu, 1985; Aksu and Mudie, 1984; Thouveny, 1988). The sediment mass accumulation in the outer fiord basins is close to 10,000 kg/m2 for these three cores, and these data are replicated in at least six other cases (Andrews and Laymon, in press; this paper). The bulk of the sediment is <63 um (Fig. 3), but the percentage of sand increases onto the shelf and into the deep-sea. There is evidence for a strong, nonlinear decrease in sediment mass accumulation from the fiords, onto the shelf, and to the deep-sea (Fig. 4). Much of the Baffin Is. eastern shelf is < 200 m in depth and is scoured by icebergs (MacLean, 1985). Sediment thickness is often < 10 m (e.g. Praeg et al., 1986; MacLean, 1985). However, sediment does accumulate on the floors of the few deep troughs that extend across the SE Baffin Shelf (i.e. HU77-156, Fig. 3, and HU78-37, Fig. 5). However, at these sites the available information (Andrews, 1987a; Praeg et al., 1986) indicates ca. <=5 m of sediment has accumulated in the last 10 ka and in the Resolution Basin, NE of the entrance of Hudson Strait, some 3 to 5 m of sediment has accumulated in the last 25 ka! Unless these sites are being largely by-passed, these rates of accumulation should set upper limits on the probably amount of sediment that has accumulated in the adjacent deep-sea basins. Indeed this appears to be true because cores in the NE Labrador Sea (Hess et al., 1987) have radiocarbon dates which indicates that < 1m of sediment has accumulated in the last 6-8 ka and less than 3 m in the last 25 ka.

The piston cores only penetrate <10% of the total sediment

thicknesses in the fiord basins (Gilbert, 1985), but they extend into, and sometimes through, the last deglacial pulse of sedimentation associated with massive meltwater discharges from the retreating Laurentide Ice Sheet (cf. Dyke, 1974). Thus the rate of sediment accumulation was an order of magnitude higher between 9 and 6 ka than at present (Andrews et al., 1985a, 1986) and was slower between ca. 9 and 12 ka. In addition, during the late Foxe Glaciation many fiord glaciers in northern Baffin Is. did not extend to the outer coast (Loken, 1966; Miller 1976, 1985; Klassen, 1985; Locke, 1987), but terminated within the fiords. In these cases, the basins would trap sediment inshore of the shelf and sediment delivery to the deep-sea would be restricted. Without drilling through the fiord basin fill, it is difficult to know the age of the basal sediment. However, extrapolation based on sedimentation rates for the last 10 ka, provides estimates in the >=14 and < 84 ka range (see later). The record of glaciation on the outer east coast of Baffin Is. (Mode et al., 1983; Miller, 1985; Feyling-Hanssen, 1985) suggests that outlet glaciers extended a short distance onto the shelf during late marine isotope stage 5 or stage 4.

Discussion:

One of the limiting age estimates above might suggest that the sediment fill was removed during the early Foxe Glaciation; this would allow consideration of the Alaskan model (Fig. 1). Conversely, the older age estimates require a different process for the advance of a fiord glacier across deep basins. Such a scenario

is sketched as Figure 6. In this model the growth of an ice sheet over the high uplands of Baffin Is. (cf. Ives et al., 1975) leads to the eventual advance of glaciers into the fiords. As the glaciers advance into deeper water the calving rate increases and may be limiting. However, the climate of Baffin Is. is arctic and the fiords are frozen solid for 9 months of the year. Thus melting and mechanical breakup of the icebergs is greatly restricted over the Alaskan case. In fiords with sills, deep-draught icebergs may be confined within the fiords. Even in this were not the case I suggest that the combination of icebergs and sea-ice causes the development of a floating mass of ice that constitutes a floating ice-shelf (Fig. 6). In a typical eastern Baffin Is. fiord (Dowdeswell and Andrews, 1985), with a calving rate of only 0.2 km/yr and the loss of half of this (probably too high) each year, then the fiord would be jammed with icebergs in a matter of a few hundred years. If there was abrupt climatic deterioration, the sea ice itself might be the seed for an ice shelf that would protect the ice front from calving more rapidly than the mass balance could accomodate.

If the ice shelf grounded on a sill, or on the shallow shelf, prior to the grounding line advancing out of the deep fiord basins then the question is: what happens to the sediment fill and confined water? One possibility is that the back-pressure allows the grounding line to advance across the deep basin and reach the outer coast and scour the basins. One negative argument for extensive sediment transportion is that the amount of re-transported sediment that has been recognized is limited. Loken (1966) and

other workers have noted shelly tills along the outer fiord walls, frequently with ages >30 ka, but the total volume of such sediment is small. An alternative is that the water in the fiord and in the sediment cannot escape during the glacier advance, hence the glacier has little or no contact with its bed. Evidence for this is seen in the low shear stresses that have been calculated for former fiord glaciers on eastern Baffin Is. using lateral moraine elevations (cf. Mode, 1980; Locke, 1980). Although normal shear stresses at the base of glaciers are around 100 kPa several reconstructions on fiord glaciers give values << 50 kPa. Such low basal shear stresses suggest that the glaciers were flowing across deformable beds (cf. Boulton and Jones, 1979; Blankenship et al., 1986; Fisher et al., 1985).

A sediment storage balance is shown as Table 1, based on a survey of the Baffin Is. fiords (Dowdeswell and Andrews, 1985; Gilbert, 1985). The error limits on this estimate are difficult to derive but are probably in the range of +/-25%. These data indicate that the fiords currently store about 2,500 km3 of sediment, which represents a total surface lowering over all of Baffin Is. of ca. 3.5 +/- m of rock. The critical question of course is: does this storage represent the last 10 ka (i.e. the Alaskan model) or does it represent a longer-term storage of sediment in these nearshore basins and the restriction of sediment inputs to the deep-sea?

SEDIMENTATION AND GLACIAL EVENTS IN EAST-CENTRAL BAFFIN Is. FIORDS

The evidence presented earlier comes from piston core data in several fiords (cf. Andrews, 1987a, Jennings, 1986) of which only one ,Tingin Fiord, is considered in this paper. The area of interest are four fiords that lie on the northern edge of Home Bay (Fig. 5) namely (from south to north): Tingin, Itirbilung, McBeth, and Inugsuin. These fiords were chosen for because of the variations in the bedrock geology (Fig. 7), particularly the variations in the outcrop of Archean granite gneisses and the younger metasediments of the Foxe Fold Belt (Tippett, 1984; Map, 198x). Table 2 lists data on the area and surface bedrock of the drainage basins that supply water and sediment to the three main fiords of this study (see Figs. 7 and 8). Other information on these fiords can be found in the one or more of the S.A.F.E. Data reparts (Syvitksi and Blakeney, 1983; Syvitski, 1984; Syvitski and Praeg, 1987).

Bathymetric data from the NOAA marine data base indicate that a deep trough angles at 45 degrees true from Home Bay. No deep trough connects McBeth Fiord and Baffin Bay.

Glacial geology:

The surficial landforms, stratigraphy, and chronology of terrestrial glacial and raised marine sediments for the area in question have been outlined by Harrison (1966), Loken (1966, 1967), King (1969), Andrews et al. (1970), Andrews (1980). Miller (1979) also visited the area and made key collections of samples for ^{14}C dating. The stratigraphy and chronology of the wave-cut stratigraphy, just to the nortn along the Clyde Foreland, is also relevant (cf. Miller,

1985; Feyling-Hanssen, 1985; Mode, 1985; Mode et al., 1983).

Figure 5 shows the location of available ^{14}C dates, whereas Figure 9 is a simplified shoreline diagram of the age/elevation relationships along a plane approximately parallel to the long axes of the fiords. These data are important to: 1) delimit the probable extent of late Foxe (Wisconsin) ice in the fiords; 2) provide some constraints on the nature of ice on the shelf; 3) provide minimum dates for the fiord basin-fills; and 4) provide information on the rate of ice retreat in the fiords.

The data break into three age groups. First there are the dates from Cape Aston, a massive raised marine delta (Loken, 1966), which indicate that it was deposited more than 52,000 years ago. This, plus the >54 ka date on whalebone from a delta on the south side of Mcbeth Fiord (Miller, 1979), and a number of "old" dates from wave-cut sections between McBeth and Itirbilung fiords (King, 1969), suggests that ice reached the outer coast >50 ka. Amino acid racemization data on shells from several of these sites indicates that most of these deposits are coeval with the Kogalu aminozone or the Ayr Lake stadial (i.e. early Foxe Glaciation). This event is currently considered to date from ca. 80 ka (cf. Andrews et al., 1985b; Miller, 1985).

There is a major depositional hiatus above present sea level between ca. 10 and 80 ka. There is, however, a suggestion that one unit on the outer coast between McBeth and Itirbilung may be equivelent to the Loks Land aminozone (Miller, person. commun. 1988; Miller, 1985) which probably dates close to 50 ka. In addition, King (1969) reported a date of 26 ka from shells in a

delta on the north side of Itirbilung. It is unclear how to interpret this date. There are several scattered ^{14}C dates in the 10-11 ka range (Figs. 5 and 9) that suggests the initial marine emergence and deglaciation started in the latest Pleistocene. However, the sites are scattered, and the relative scarcity of shells in this age range may imply that nearshore mraine conditions were severe with limited sediment input for the construction of deltas and beaches.

In outer McBeth and Itirbilung, and at the head of Tingin, dates on the major raised deltaic sequences are between 9.1 and 8.7 ka (NOTE: all shell dates have been corrected for reservoir effects), whereas the delta at the head of Inugsuin is dated at 7.5 ka (Loken, 1967). There are few dates along the fiord walls (Fig. 5) and deglaciation of the head of McBeth is unknown. The marine limit at the head of Inugsuin is 65 m (Loken, 1967) and the marine limit on the north side of McBeth, near the fiord head, is ca. 60 masl. Glacial tectonized sediment was discovered on the south side of McBeth in 1983 by Boulton and Andrews. Unfortunately, the enclosed shell samples were contaminated by an unknown source (Andrews and Laymon, 1988); samples close by, but at a lower elevation, were collected by Stravers in 1987 and dated ca. 5 ka. At the head of Itirbilung, massive clays, probably marine, extend to a maximum of 43 masl. Age estimates for the deglaciation of the heads of Itirbilung and McBeth can be developed from the regional shoreline and rebound patterns (Loken, 1967; King, 1969; Andrews et al., 1970). Such estimates indicate that the ice retreated onto land between 7 and 8 ka. In all these fiords, massive valley-fills

of marine sediments and outwash sands and gravels extend to the local marine limit. During subsequent glacial isostatic rebound Fig. 9),the major rivers have eroded these valley-fills and moved the sediment onto and acrcss the pro-delta.

Local glaciers and ice caps developed during the Neoglaciation (Andrews, 1982; Davis, 1985). Small glaciers reach tidewater along these fiords (Fig. 8) and built ice-cored moraine complexes. During the 1983 Hudson cruise I was able to visit some of these glaciers and estimate the age of the readvance(s) by lichenometry. Previously, Harrison (1966) discussed the chronology of neoglaciation in the valley north of core site HU83-MC4.1 (Fig. 5)(Siward Glacier) and King (1969) had measured lichens on moraines near Itirbilung fiord. Harrison's work documented a series of proglacial lake shorelines and end moraines; the latest advance occurred between 1790 and 1820 AD with one older neoglacial advance, bearing Rhizocarpon geographicums.s.l. diameters of 45 mm(ca. 900-1150 BP). On the south side of the fiord, tidewater glaciers with moraines with lichens dating from about 900, 300 and 100 BP were mapped.

In summary, the glacial geology and raised marine evidence indicates that the outermost parts of the fiord were not glaciated during the late Foxe Glaciation. Ice may have been in the outer fiords ca. 10-11 ka and by 8.7 ka copious sediment was being deposited in ice-proximal deltaic sequences. The retreat of the outlet glacier in McBeth was 30 m/yr. This figure is higher than estimates from Home Bay (Andrews et al., 1970) of between 10 and 20m/yr.

FIORD AND SHELF CORES AND CHRONOLOGIES

Figure 5 shows the location of the piston cores that are dealt with in this paper. In addition to cores from the fiords I will also discuss two cores from the adjacent shelf, namely HU78-36 and HU78-37. The former core occurs east of Cape Aston (Figs. 2 & 5) whereas HU78-37 is located on the shelf, just south of Home Bay.

There are two significant issues to be considered when discussing sediment rates from cores in these environments. These are: 1) how reliable are the ^{14}C dates; and 2) how complete is the core recovery (put another way--does the piston core top date from present?). These are two seperate questions and neither can be answered with 100% confidence. Question #1 has been examined in several recent papers (e.g. Fillon et al., 1981; Andrews et al., 1985a) and this paper does not add much new insight into the problem of evaluating ^{14}C dates on the acid-insoluble total organic matter (AIOM) fraction. Shells were very rare to absent in the cores. In three cases (Table 3) shells were used for dating, but in all other cases the AIOM fraction had to be used. The palynology of HU83-MC4.1 and MCIT3.1 (Short et al., subm., Andrews, 1987b) indicates that, at the levels dated, the amount of Pre-Quaternary pollen in the cores was very low. Thus contamination by "old" carbon is not as easy to document as it was for two other cores (Andrews et al., 1985a). Neveretheless, I feel that the AIOM dates are too old, or at best "less than or equal to". Thus for this

paper I use reservoir corrected shell dates and corrected (Andrews et al., 1985a) AIOM dates (Table 3). Examination of 6 cores along the shelf and fiords indicated a peak in Dinoflagellates (Short et al., sumb.) that was dated in several cores at ca. 5 ka. The synchrony of this event, and others (Jennings, 1986), suggests that the corrected AIOM dates are "reasonable" estimates.

There are two measures of the problem of the recovery of the upper section of sediment. One is the difference in length between the recovered sediment and the length of penetration of the coring barrel (Table 4). The other is the similarity between the upper 1-2 m of sediment in the piston core, compared with a 11 cm diameter Lehigh gravity core from the same station. A rigorous analysis of the problem is not conducted in this paper, suffice to note that the probability is that sediment has been by-passed. It is assumed in Figure 10 that the surface of the piston cores dates from 500 BP.

The ^{14}C dates (Table 3) indicate that deposition was occcurring on the shelf between 11 and 12 ka. The corrected date from the base of HU83-MC83.6 suggests that deposition in the outer north arm of McBeth was underway by ca. 13 ka and the corrected dates from the distal fiord basins all suggest that these sediments were deposited <=10.5 ka. Figure 10 shows depth/age data for the fiord cores. These curves indicate the expected--there is high sediment inputs near the fiord heads (IT1.1), and these decrease to the outer fiord (MC83.6). Average net sedimentation rates vary between 1.5 m/ka to 0.23m/ka. At ODP Site 645, just to the NE (Fig. 2) the Pleistocene sedimentation rate is either ca. 0.15m/ka or 6-9

times smaller (cf. de Vernal et al., 1987).

The critical question at this stage is whether we can reasonably extrapolate back in time from the sediment accumulation curves (Fig. 10) to the base of the seismic section? The concept of paraglaciation (Church and Ryder, 1972), and our knowledge of melt rates of the Laurentide Ice Sheet, suggests that the highest rates of sediment accumulation would occur during deglaciation, that is between ca. 9 and 6 ka. The data (Fig. 10) and others (Andrews et al., 1985a; Jennings, 1986; Horvath, 1986) indicate maximum accumulation rates in this interval. Thus a conservative measure of the age of the base of the section may be derived by extrapolating the deglacial rates.

ACOUSTIC STRATIGRAPHY OF SOME FIORD BASINS

High resolution Huntec deep-tow system (DTS) and airgun records were run in along the axes of the fiords (cf. Gilbert, 1985; Syvistki, 1984; Jennings, 1986). Interpretation of these records is not straight-forward because of interference from fiord-walls, and the lack of a 3-D perspective on the geometry of the acoustic units. In particular, the influence of sediment sources from valley walls and side-valleys is difficult to evaluate. The two basic questions of interest in this paper are: 1) what is the total thickness of sediment in the fiords, particularly at the piston cores sites?; and 2) what is the nature of the acoustic records and how do they translate into the core lithostratigraphy? The overriding question

is the age and nature of the basal sediment fill.

During the 1983 cruise CSS Hudson entered McBeth Fiord in daylight. There was little evidence of basinal sediments in the north arm until up-fiord from a series of lateral moraines and deltaic deposits that were described and dated by King (1969). This transition is associated with a bedrock sill. On the proximal side of this feature the Huntec record (Fig. 11) suggests that sediment was overridden by ice (in Syvitski, 1984). Up-fiord the sediment is ponded in a series of basins with little evidence for sediment draping. At HU83-MC4.1 (Fig. 11) at least 50 m of acoustically laminated sediment lies beneath the base of the core. The frequency of parallel acoustic laminations increases toward the surface. HU82-MC7 appears to penetrate a slide, although the paleomagnetic record (Andrews et al., 1986) indicates that the upper 4 m is primarily in situ. HU83-MC83.6 (Fig. 5) was cored on a rise in the fiord and should thus have a low sedimentation rate. The Huntec record sugggests the occurrence of 10-15 m of rather weakly laminated sediments, possibly overlying a diamicton. Thus, in the outer reaches of the McBeth there is little evidence for diamictons within the basinal sequences and it is difficult to trace major seismic reflectors from one basin to the next.

Syvitksi (1984) interpreted the Huntec DTS records from Itirbilung. Seaward from IT3.1 (Fig. 5) the seismic stratigraphy is complex and suggests that the base of the section consists of diamictons, overlain by acoustically laminated sediments with a drape of more transparent sediments completing the section. There are some well defined reflectors within Itirbilung that have some

axial continuity. Close to HU83-IT2.3 Syvitki(1984, Fig. 16-13) suggests that "Disturbed (overridden)?" sediments underlie "debris flows?" with a thick sequence of acoustically laminated sediments forming the upper 15-20 m. Radiocarbon dates on shells from the north shore of Itirbilung Fiord (Fig. 5) suggests that a minimum date for the till/glacial-marine contact near HU83-IT3.1 should be >=9.1 ka. The deglacial history of the area suggests that a major change in the rate of sedimentation should have occurred when the retreating outlet glaciers reached the heads of the fiords, that is as early as 8.7 ka for Tingin and ca. 7.5 ka in Itirbilung, McBeth, and Inugsuin (Fig. 5). Figure 12 is a trace of the Huntec DTS record between HU83-IT3.1 and HU83-It2.3.

The evidence from these two fiords is not conclusive but there is some suggestion that sediment was overridden in McBeth (Fig. 11) and till may interfinger with glacial marine sediments in part of Itirbilung (Syvitski, 1984). The thickness of the section beneath the piston cores varies but Table 5 represents best estimates for each core site. The age of the bedrock/sediment or till/sediment interface is estimated by extrapolation (see above) from the two lowermost dates in each core, and an age estimate is derived based on a postulated maximum sediment accumulation of 5 m/ka. In some cases the Huntec records from 1982 and 1983 are difficult to compare (cf. Syvitksi, 1984) and a range of sediment thickness is therefore shown. The results of this crude analysis (Table 5) either suggest that sediment has been stored in the fiords during the late Foxe Glaciation, or that sedimentation rates are being badly underestimated. This could only be due to the ^{14}C

dates, even after corrections (cf. Andrews et al., 1985a), being still significantly too old. I do not feel that this is the case. Analysis of the amount of Pre-Quaternary pollen in the cores (Short et al., subm.) indicates that in HU83-MC4.1 the basal date comes from sediment with few Pre-Quaternary pollen grains, hence contamination by "old" carbon, although still probable, is not de facto. On Table 5 I have also made a rough calculation of the required rate of basin infilling <u>assuming</u> that the fill has only accumulated since deglaciation, that is between 10 ka in the outer fiords and 7 ka at the heads. This calculation requires sedimentation rates to <u>average</u> 5 m/ka in all basins except for HU83-MC83.6.

Existing data can not truly resolve the question of the rate of sediment infilling. What is required is the operation of the "long-coring facility" in the outer fiord basins. With cores of 20-30 m in length, and with the AMS ^{14}C facilties, it is probable that sufficient shell and/or foraminifera can be recovered for more reliable dates. In addition, Huntec DTS profiles are required <u>across</u> the fiords to obtain better data on sediment geometries.

REGIONAL VERSUS LOCAL SEDIMENT SOURCES

The last section of this paper deals with the style and source of fiord sediments in the outer basins. Given the information in Table 5 then one approach would be to suggest that the piston cores only retrieved sediment that spans < 5 ka. We can investigate this

hypothesis by examining the lithostratigraphy of the cores and indicators of sediment provenance, keeping in mind the broad regional bedrock geology (Fig. 7). Previously, Andrews and Jennings (1987) noted that the magnetic susceptibility (MS) of sediments derived from the Foxe Fold Belt were very low in comparison with sediments derived from the Archean region of the shield. Table 2 lists the basin areas which supply water and sediment to the fiords (Fig. 8) and the percentages of Foxe Fold Belt or Archean bedrock within each drainage (Fig. 7).

Core descriptions from the area are given by Hein and Longstaffe (1985), Andrews et al. (1986), Hein (1987) and in various chapters of the S.A.F.E. reports. Figure 13 illustrates the core stratigraphy and the downcore log of the volume magnetic susceptibility (MS) (cf. Andrews and Jennings, 1987). The core descriptions are based on X-radiography and visual inspection of the archive-half of the core. Terminology follows Eyles et al. (1985).

The cores consist primarily of fine-grained burrowed to massive (Fm(b)) sediments with frequent small sand beds, often graded. Toward the base of most cores (see also Jennings, 1986) there is a fine-grained laminated (Fl) unit (Fig. 13). In Clark Fiord, Jennings (1986) noted that the number of beds in the Fl unit was approximately equal to the number of radiocarbon years allowed for deposition. The cores show a general upward sequence of Fl followed by Fm(b). Farrow et al. (1984, subm.) discuss the present-day conditions that promote burrowing of the sediment by a variety of organisms, this is related to nutrients and the well-oxygenated bottom waters in the fiords. The presence of

bioturbation also places some upward limits on the rate of sediment accumulation. The conditions under which the Fl units were deposited are not clear. Ekdale and Mason (1988) suggest that one possible scenario would be anoxic conditions. Such conditions may indeed prevail in polar areas where a permanent ice cover (sea-ice or ice shelf) restricts the typical fiord/estuarine circulation. If such an environmental model is appropriate then core stratigraphies (Fig. 13) suggests that this environment was followed by increased oxygenated conditions and the establishment on an active in fauna (cf. Farrow et al., 1984, subm.). The number of individual sand units varies between fiords and generally decreases seaward. These beds represent individual events associated with sediment transport along the axis of the fiord or from the fiord walls.

The question next addressed is the change(s) is sediment during the time-span of the cores. If the cores represent rapid sedimentation under current conditions then I hypothesize that the sediment provenance should remain relatively constant with depth(=time). Conversely, major changes in provenance may be associated with regional changes in extent and volume of ice. The parameter chosen to investigate this question was the magnetic susceptibility of the sediment (Thompson and Morton, 1979, Bradshaw and Thompson, 1985; Dearing et al., 1981; Tarling, 1983).

The magnetic susceptibility (MS) of surface sediments in the fiords (Andrews and Jennings, 1987) indicates that there is a major difference in MS between sediments at the head of fiords that lie all or mainly within the Foxe Fold Belt. Values (all values quoted as SI units x 10 -5, Figs. 13 & 14) are between 10 and 20 SI

at the head of Itirbilung and Tingin fiords compared with >200 SI in Inugsuin and further north in Cambridge Fiord. Although MS is moderately correlated with grain-size (Andrews and Jennings, 1987), such that finer-grained sediments have lower MS readings, variations in grain-size do not swamp the order of magnitude difference between these two major bedrock types. In Figure 14 a qualitative "mixing line" is drawn that joins 100 % Foxe Fold Belt MS values with those totally within the Shield granites/gneisses. The central value and range of MS readings from the cores (Fig. 5) are plotted along this line; individual downcore MS logs are shown on Figure 13. On the basis of present surface samples three categories of sediment source are delimited Fig. 14); switches from one mode to another are shown on Figure 13. An important aspect of IT2.3, IT3.1, and MC4.1 is the Foxe Fold Belt signature at the base of the cores. In HU83-MC83.6, I suggest that this unit occurs in the middle of the section (Fig. 13), with an age at the top of the section of ca 9 ka, approximately the same age at the low MS readings in the other cores. I suggest that these data must be associated with the period of maximum glacial expansion where ice was being channelled into the fiords after a sustained flow across the interior outcrop of the Foxe Fold Belt. This episode was followed in Itirbilung and McBeth fiords with the input of sediment that was more mixed or more definitely from an Archean source (Figs. 13 & 14). This indicates that the contribution of sediment from local mountain glaciers and ice caps (Fig. 5) increased proportionally. This change would only occur after 7 ka, at the time when the ice sheet lay landward of the fiord heads (cf. Dyke, 1974; Andrews et al., 1970). The southern shelf

core, HU78-37) lies in an area where there is a plume of low MS (on surface sediments (Andrews and Jennings, 1987)). Figure 13 indicates that this interval covered the last several thousands of years, although some of the low MS in the core may also reflect increase in organic carbon and diatom numbers.

The analysis of the core lithologies and provenance (or at least once measure) strongly suggests that the interval covered by the piston cores is of the order of 10 ka rather than 5 ka. Thus, it is indeed possible that some fiord basins retained sediment during the last glacial advance. The evidence in this paper does not allow a more categorial statement to be made.

CONCLUSIONS

The landscapes of Baffin Is. partly reflect glacial erosion, but at the regional scale large areas (42 % of the total) show little evidence of glacial erosion (Andrews et al., 1985c). Areas of intense glacial scour, as shown by the density of small, strucurally controlled rock-basins (Sugden, 1977; Andrews et al., 1985c) lie toward Foxe Basin or are concentrated at the heads of fiords. Aerially sustained average rates of denudation of 220 mm/yr (Table 1) are difficult to reconcile with the regional geomorphology. In addition, Harbour et al. (1988) have shown that a reasonable glaciological model of glacial erosion requires 10^5 yr for creation of a U-shaped valley, i.e. rather a long period of time.

The morphology of the Baffin Is. continental shelf is significantly different from those along the Labrador coast or off

West Greenland. A striking feature of the Baffin Is. shelf is the absence of the coast-parallel troughs that mark the Tertiary/basement contact. These deep marginal troughs suggest the presence of grounded and erosive glacial ice on the shelf (e.g. Josehans et al., 1986). I propose that the absence of these features on the Baffin Is. shelf implies the contrary condition (i.e. that the shelf was not covered by thick grounded ice).

The lack of deep troughs connecting every fiord to the shelf slope indicates that the sediment supply from the fiords to the deep-sea would be restricted to either a few major routes, or to times when grounded ice lay at the shelf edge. In the terrestrial record, the evidence for the latter is not at all clear, as tills have not been recognized in the wave-cut outcrops along the outer coast (Mode et al., 1983; Feyling-Hanssen, 1985). However, the analysis of the ODP 645 data (Srivastava et al., 1987) indicates that the detrital carbonate-rich sediments are the "glacial" indicators. This implies that during the glacial intervals the supply of sediment to the deep sea was not dominated by sediment transfers from the east-central fiords because the carbonate content of these sediments if usually < 2% (e.g. Jennings, 1986).

The low shear stresses ascribed to some former outlet glaciers on Baffin Is. suggests that the ice may have moved on a deforming bed (e.g. Boulton and Jones, 1979) of silty-clay with a relatively high moisture content. Whether any of the structures and some reflectors in the fiords represent such units is an important question that this paper cannot answer.

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TABLE 1

Order of magnitude estimate of sediment volume stored in the fiords of eastern Baffin Island and amount of glacial erosion

Number of fiords ca. 250 (Dowdeswell and Andrews, 1985)

Average surface area of these fiords 100 km 2 (Dowdeswell and Andrews, 1985)

Maximum sediment thickness < 200 m (Gilbert, 1985)

Average sediment thickness ca. 100 m (Gilbert, 1985)

Total sediment volume 2,500 km3

Area Baffin Island 450,000 km2

Thickness of sediment if spread evenly across the island <=5.5 m

Bedrock lowering (assumed density of 2700 kg m3) <=3.4 m

Rate of bedrock lowering if this associated
with late Foxe=3400mm/ca.15 ka= ca. 220mm/ka, range 110-340mm/ka

TABLE 2

Information on drainage basin areas (km 2) (see Fig. 8)(from Gilbert and MacLean, 1983 in: Syvitski and Blakeney, 1983, and in: Syvitski, 1984).

Basin # (Fig. 8)	Tingin	Itirbilung	McBeth	%Foxe Fold Belt
Total drainage	1261	2242	4038	
Fiord area	218	162	402	
1	302	141	1664	100,26,88.5
2	140	1243	278	100,97.6,2
3	179	327	247	100,28.8,0
4	35	243	347	100,0,0
5	143	286	335	100,0,0
6	92		234	100, 71.4
7	370		362	100, 16.1
8			103	0
9			463	0

TABLE 3

Uncorrected and corrected radiocarbon dates from cores. Lab. AA is an AMS facility

Core# (Fig. 5)	Depth(cm) in core	Material*	Lab#	Reported Date	Corrected Date
HU-					
78-36	62-68	S	GX-6280	11,770	11,420
78-37	215	O	GX-8755	8,285	5,680
	437	O	GX-8756	12,035	8,100
	569	O	GX-6608	16,360	10,900
83-MC83.6	85-88	O	AA-1012	12,970	8,730
	292	O	AA-0654	19,200	12,800
83-MC4.1	80-82	O	AA-1011	2,819	2,410
	325	S	AA-1801	4,780	4,370
	782-786	O	AA-0653	16,700	11,150
83-IT1.1	593	S	AA-1917	3,920	3,510
83-IT2.3	100-102	O	AA-2276	5,084	3,670
	370-375	O	AA-2275	8,390	5,750
	841-845	O	AA-1523	15,800	10,560

83-IT3.1		O	AA-		
	445-452	O	AA-0935	13,500	9,080
82-TI3	137-142	O	GX-11335	5,185	3,670
	364-384	O	GX-9434	10,430	7,080
	1077-1108	O	AA-0190	12,890	8,680

*S= shell; O=acid-insoluble organic matter (Kihl, 1975)

TABLE 4

Information on the cores (see Fig. 5)

Core#	Lat & Long	Water depth(m)	Core penetration(A)	Core length(B)	Ratio B/A
78-36	70 08.08, 66 48.07	99	NA	99	NA
MC83.6	69 40.7, 69 09.8	429	450	306	0.68
MC7	69 37.5, 69 16.	497	NA	1121	NA
MC4.1	69 31.4, 69 57.	549	810	610	0.75
IT3.1	69 17.6, 68 12.3	365	810	483	0.6
IT2.3	69 17.5, 68 27.	410	853	610	0.72
IT1.1	69 20., 69 03.8	256	900	793	0.88
TI3	69 11.5, 68 23.5	487	NA	1108	NA
78-37	68 15.05, 65 12.09	457	NA	593	NA

NB. Cores MC7 and TI3 were collected in 1982, whereas MC83.6,MC4.1,It3.1,IT2.3 and IT1.1 were raised in 1983.

TABLE 5

Estimated dates at the bedrock/sediment or till/sediment interface beneath the core sites in Tingin, Itirbilung and McBeth fiords.

Core #	Piston core basal date,ka	Max. sed. rate (m/ka)*	Section thickness	Estimated age,ka	Min. age (#)
MC83.6	12.8	0.5	10	33	NA(1 m/ka
MC4.1	11.2	0.68	50+/-	84	22(5 m/ka
IT3.1	9.1		15-60?		(5 m/ka
IT2.3	10.6	0.97	15-40	25-51	16(5m/ka)
IT1.1	3.5	1.7	40+/-	26	11(5 m/ka
TI3.1	8.7	4.6	>40?	14	17(5 m/ka

* Calculated between the lower two dates in a core.

Based on 5 m/ka for sedimentation rate below base of piston core. Figures in brackets (e.g. 1 m/ka) refers to required sedimentation rate averaged over the last 7 - 10 ka (i.e. since deglaciation).

FIGURE CAPTIONS

FIG. 1: Schematic illustration of the "Alaskan" model for an advance of a glacier down a fiord. To reduce the calving rate the glacier can only advance if a moraine shoal is constructed at the glacier front.

FIG. 2: Location map of the area of study, showing the location of the fiords and piston cores from the shelf.

FIG. 3: Sediment accumulation at sites along the eastern continental margin of Baffin Is. showing the proportion of sand/silt/clay in the fiord, shelf, and deep-sea environments.

FIG. 4: Range of sediment accumulation over the last 8 ka in a transect from the fiords,shelf, to the deep-sea off eastern Baffin Is..

FIG. 5: Location map of the fiord area of east-central Baffin Is..

FIG. 6: An "arctic" model for fiord glacier re-advance in which rapid iceberg calving and seasonal fast-ice results in an ice shelf.

FIG. 7: Generalized bedrock map of the east-central fiord area showing the extent of the Foxe Fold Belt and the Henry Kater gneissic complex.

FIG. 8: Drainage basins, location of tidewater glaciers, and major fluvial inputs for the east-central fiords (from Gilbert and MacLean, 1983; Syvitski, 1984).

FIG. 9: Simplified shoreline diagram (from Andrews, 1980) from

the east-central fiord area showing the elevation and age of dated marine deposits and the location of moraines of Cockburn age.

FIG. 10: Age/depth diagram for piston cores from the east-central fiords. Location of the piston cores is shown on Fig. 5.

FIG. 11: Interpreted Huntec DTS record from the outer, southern branch of McBeth Fiord. The location of this profile is shown on Fig. 7. Note the break in the profile.

FIG. 12: Interpreted Huntec DTS record from Itirbilung Fiord between HU83-IT3.1 and HU83-It2.3. Location of the profile is shown on Fig. 7.

FIG. 13: Down-core lithostratigraphy of the piston cores and the volume magnetic susceptibility (MS). MS measured on the core archive using a Bartington MS loop. Units are x 10 -5 SI. The different patterns reflect MS readings in the Foxe Fold Belt, mixed, or Archean provenance (see Fig. 14).

FIG. 14: Diagram of the variations in the magnetic susceptibility of piston cores with respect to a "mixing line" that indicates the trend from 100% Foxe Fold Belt derived sediment to 100% Archean.

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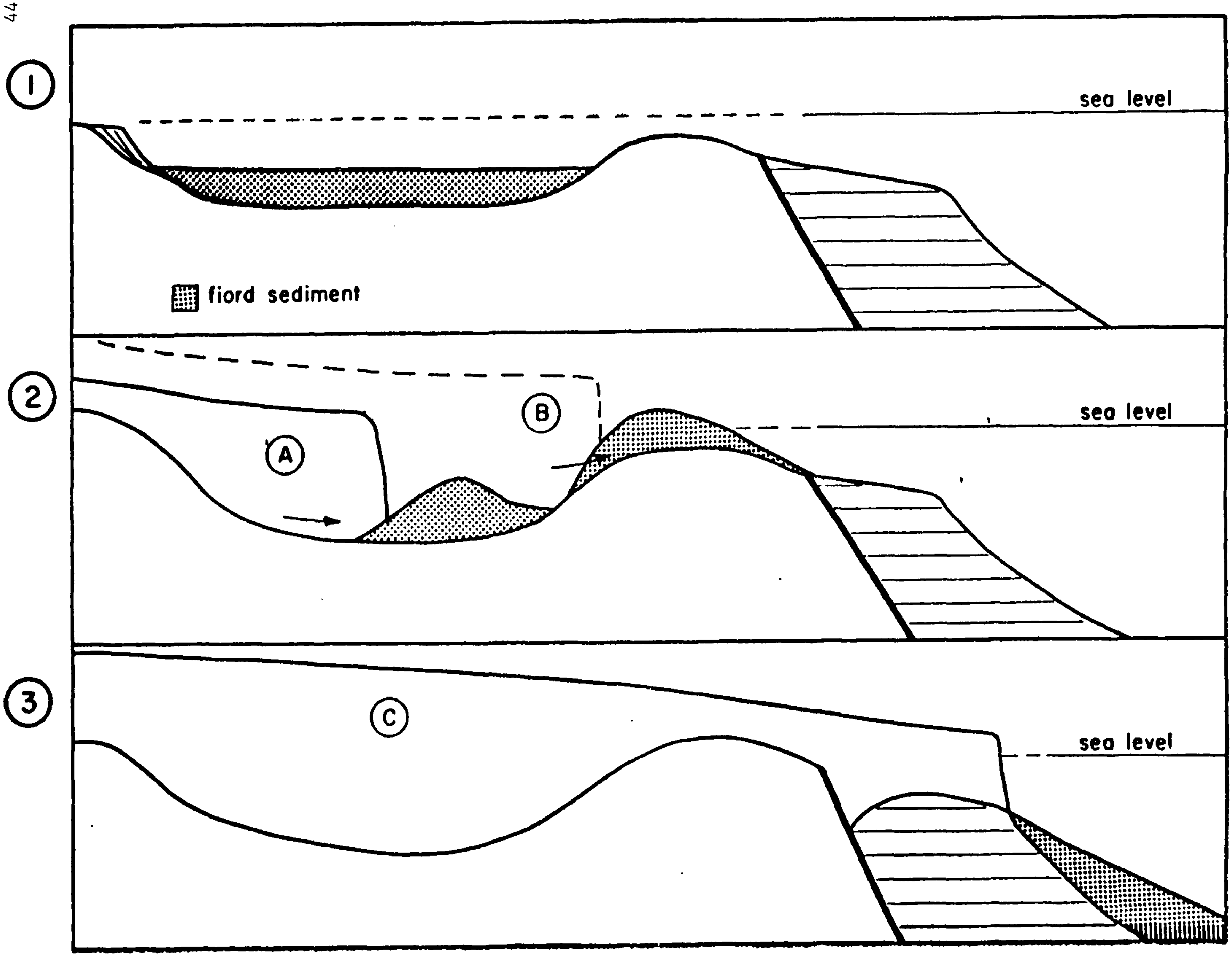
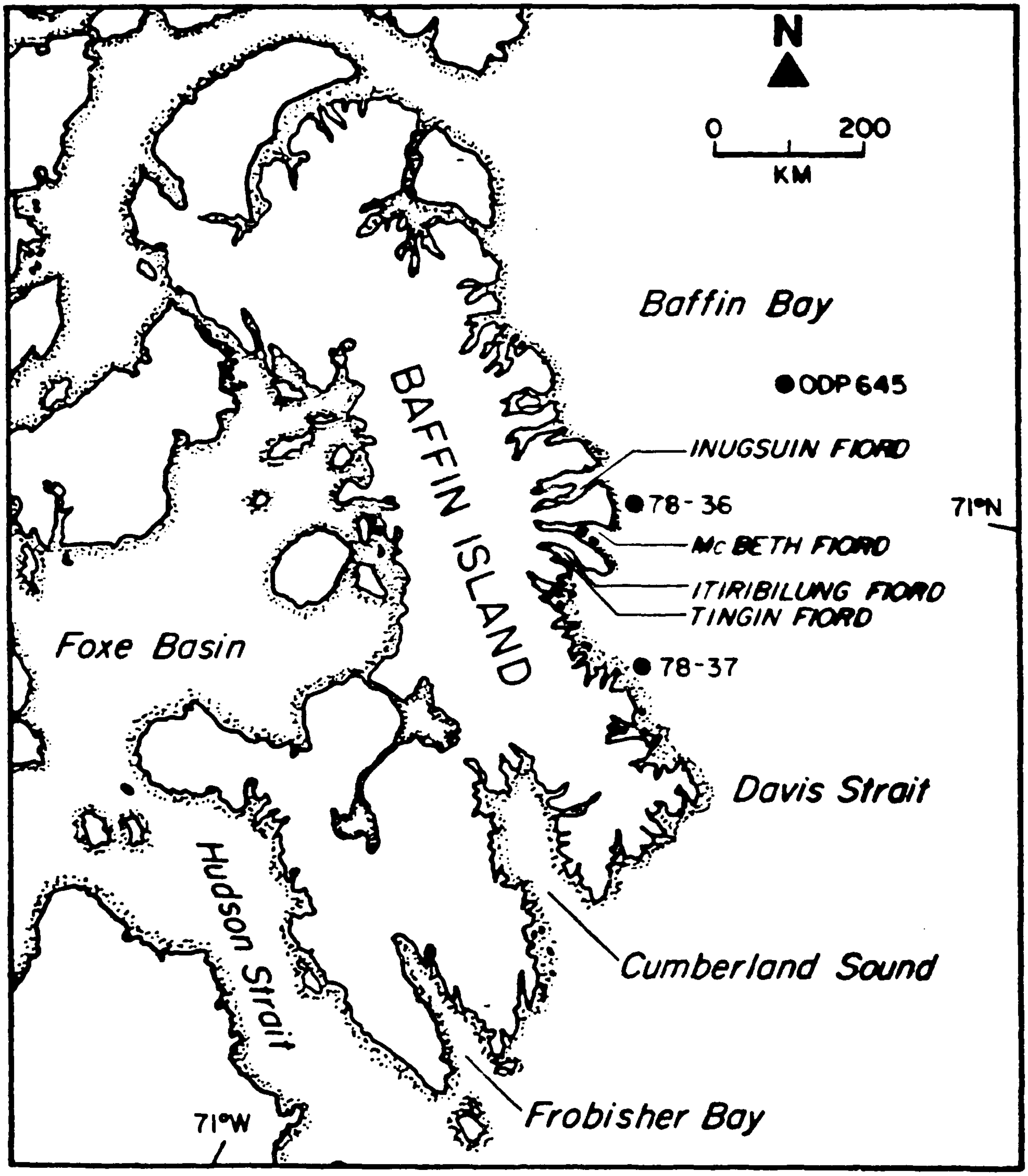
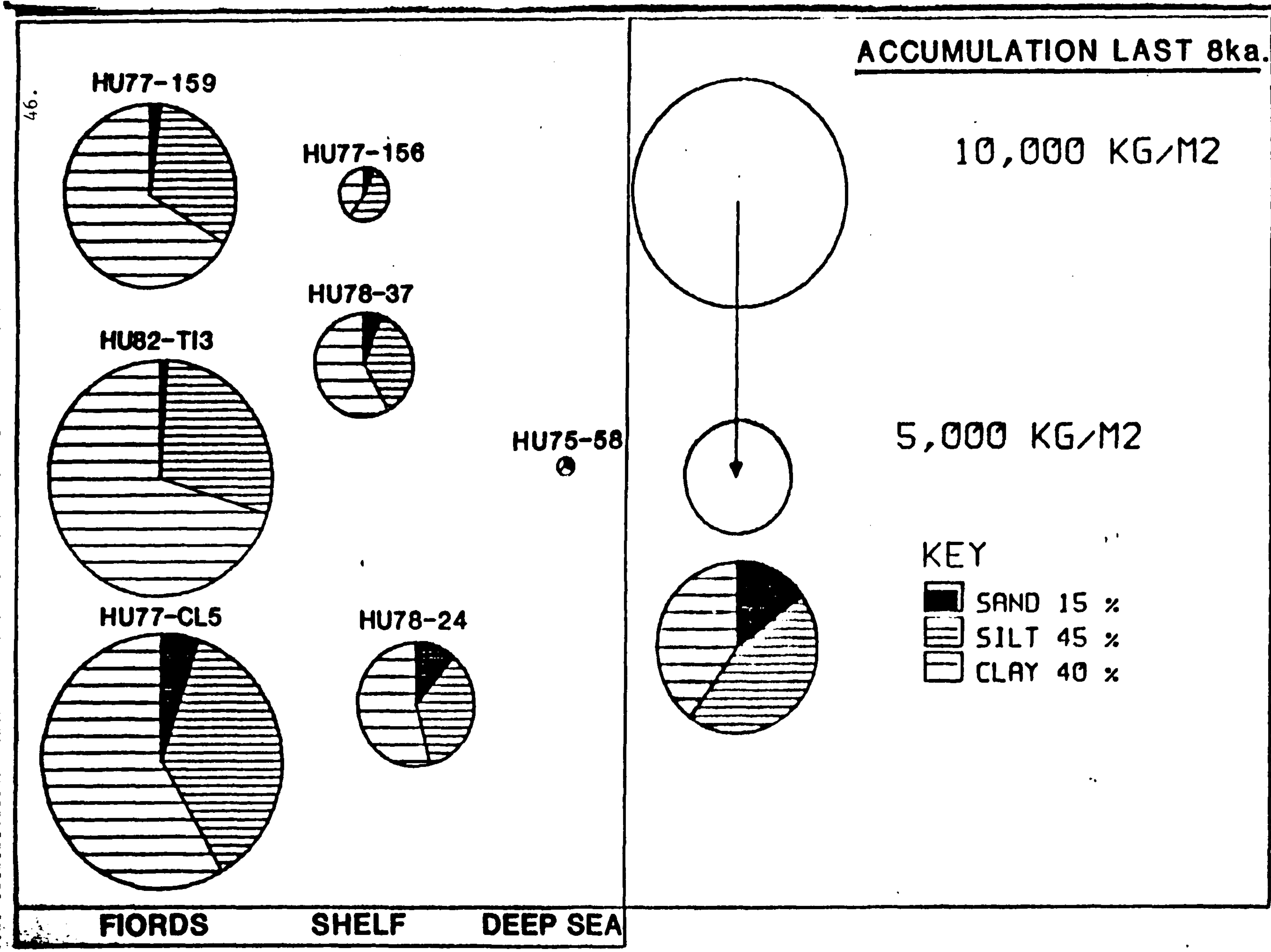
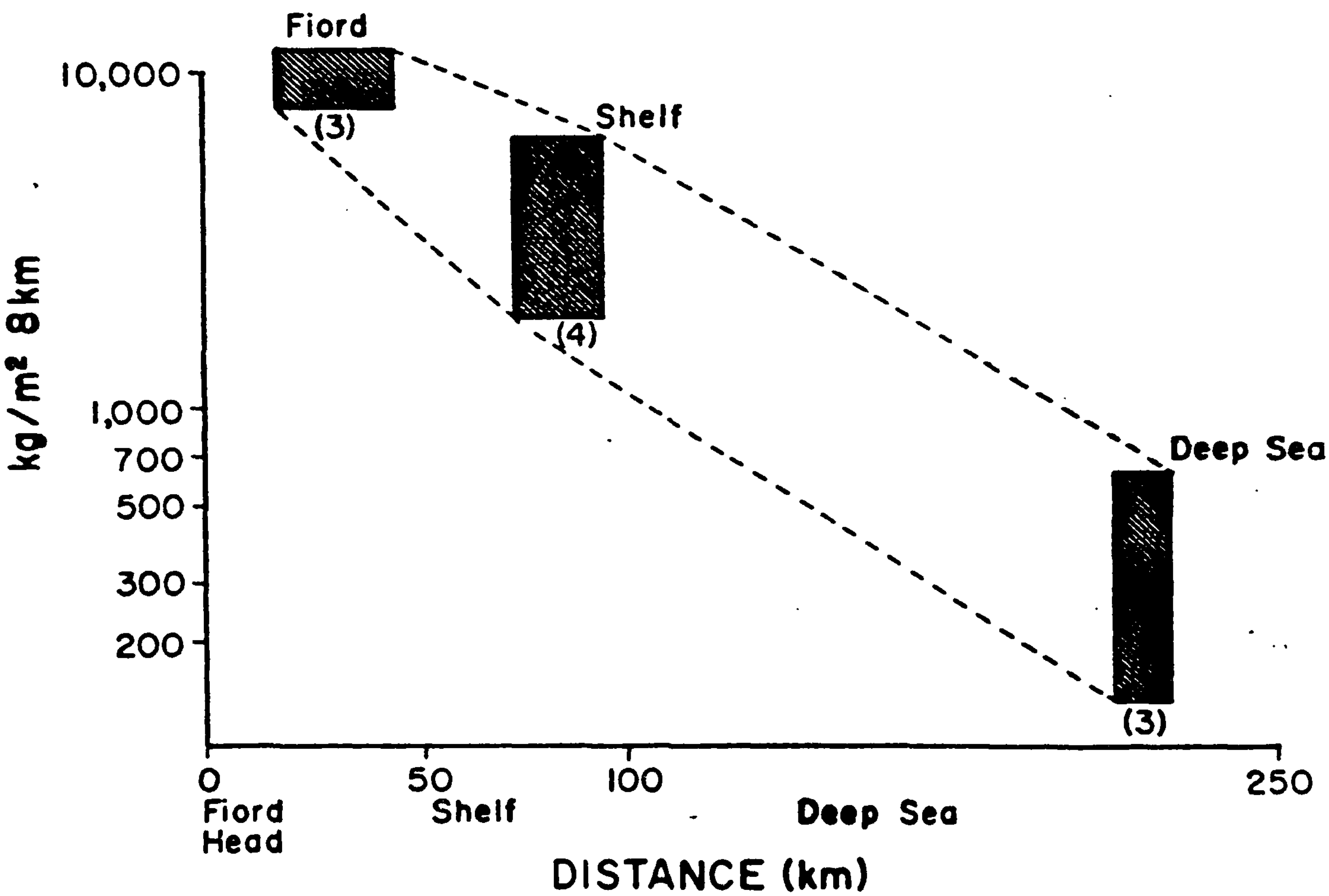

1
sea level
fiord sediment
2
sea level
A
B
3
sea level
C

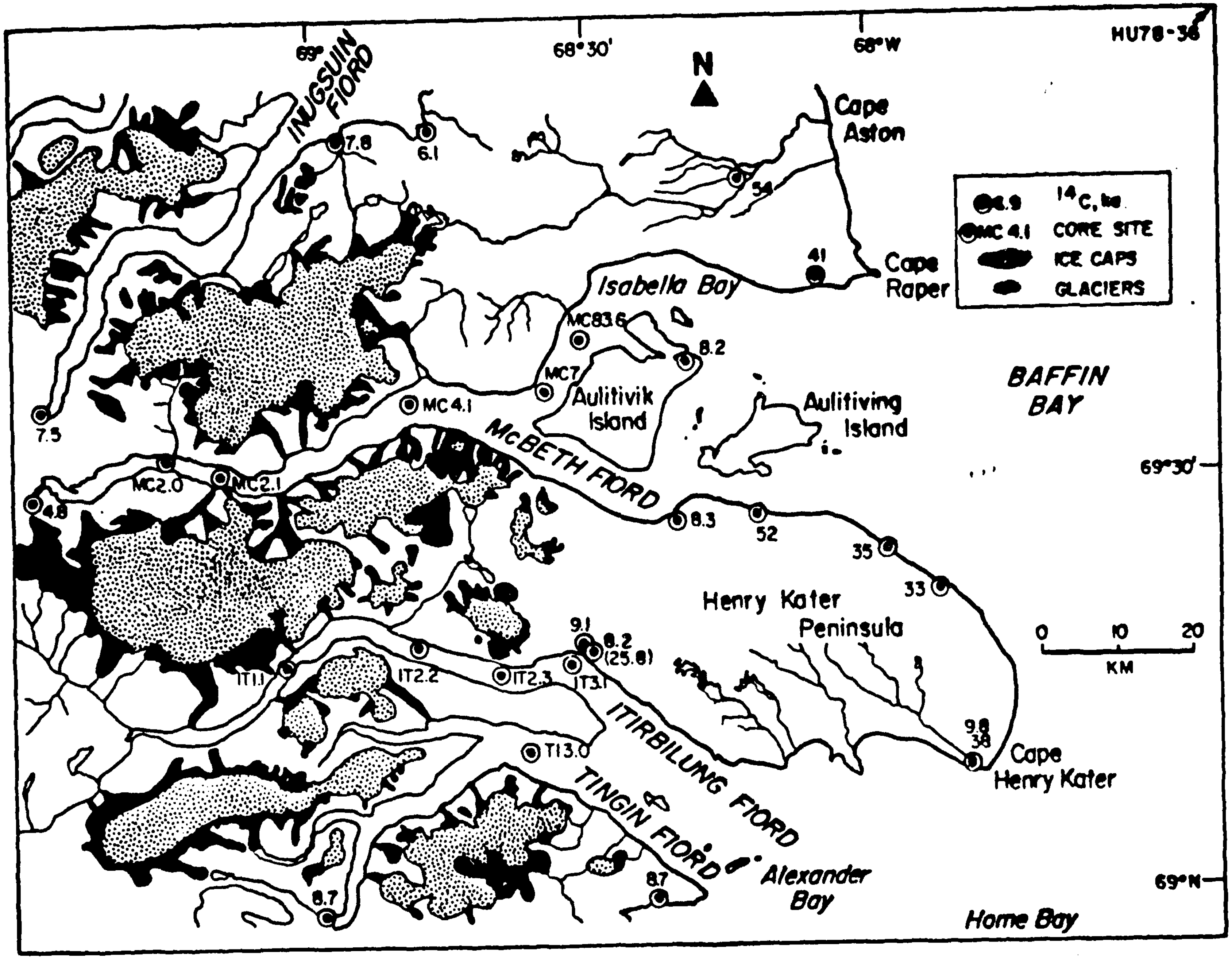


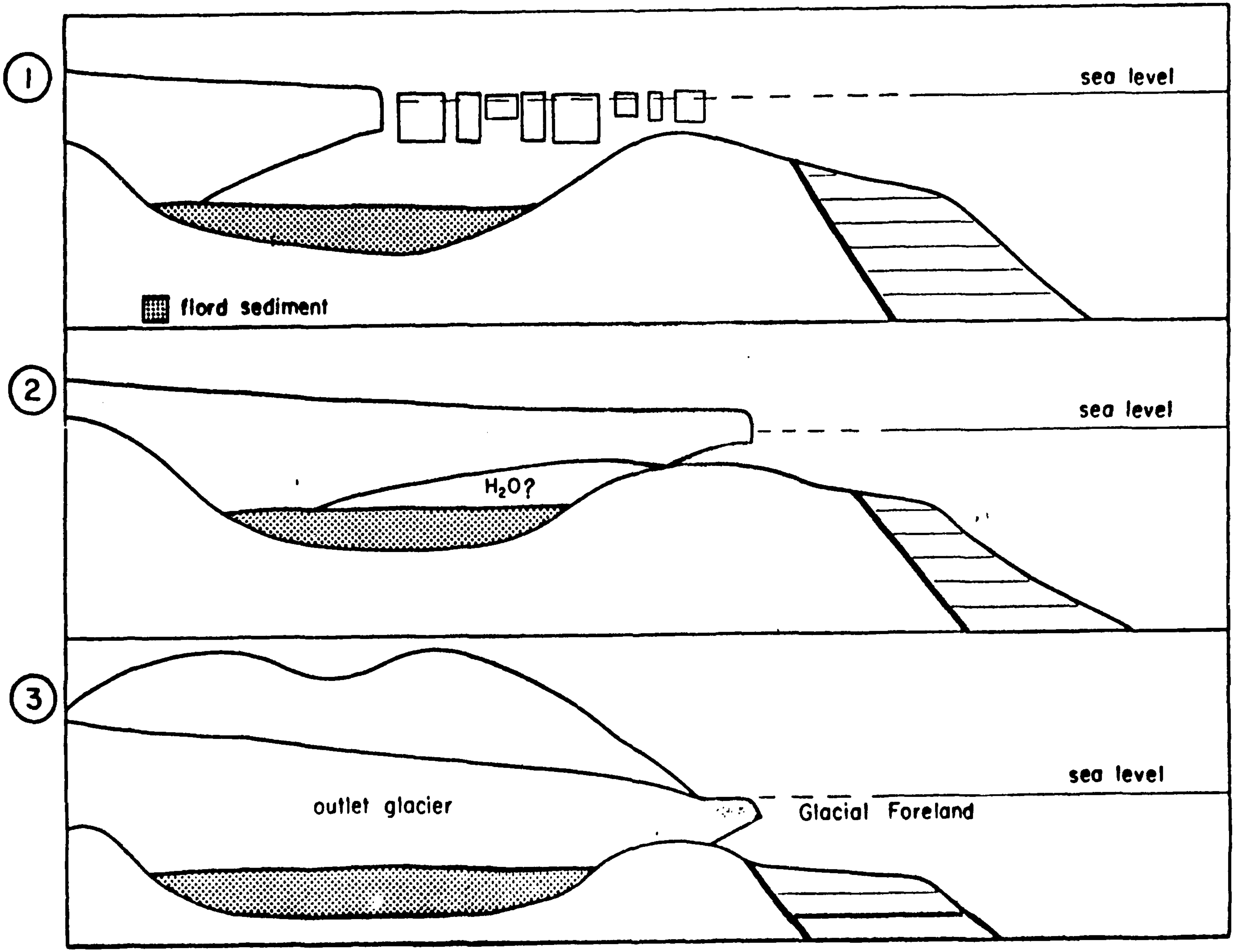
N
0
200
KM
Baffin Bay
ODP645
INUGSUIN FIORD
78-36
71°N
Mc BETH FIORD
ITIRIBILUNG FIORD
TINGIN FIORD
78-37
BAFFIN ISLAND
Foxe Basin
Davis Strait
Cumberland Sound
Hudson Strait
Frobisher Bay
71°W

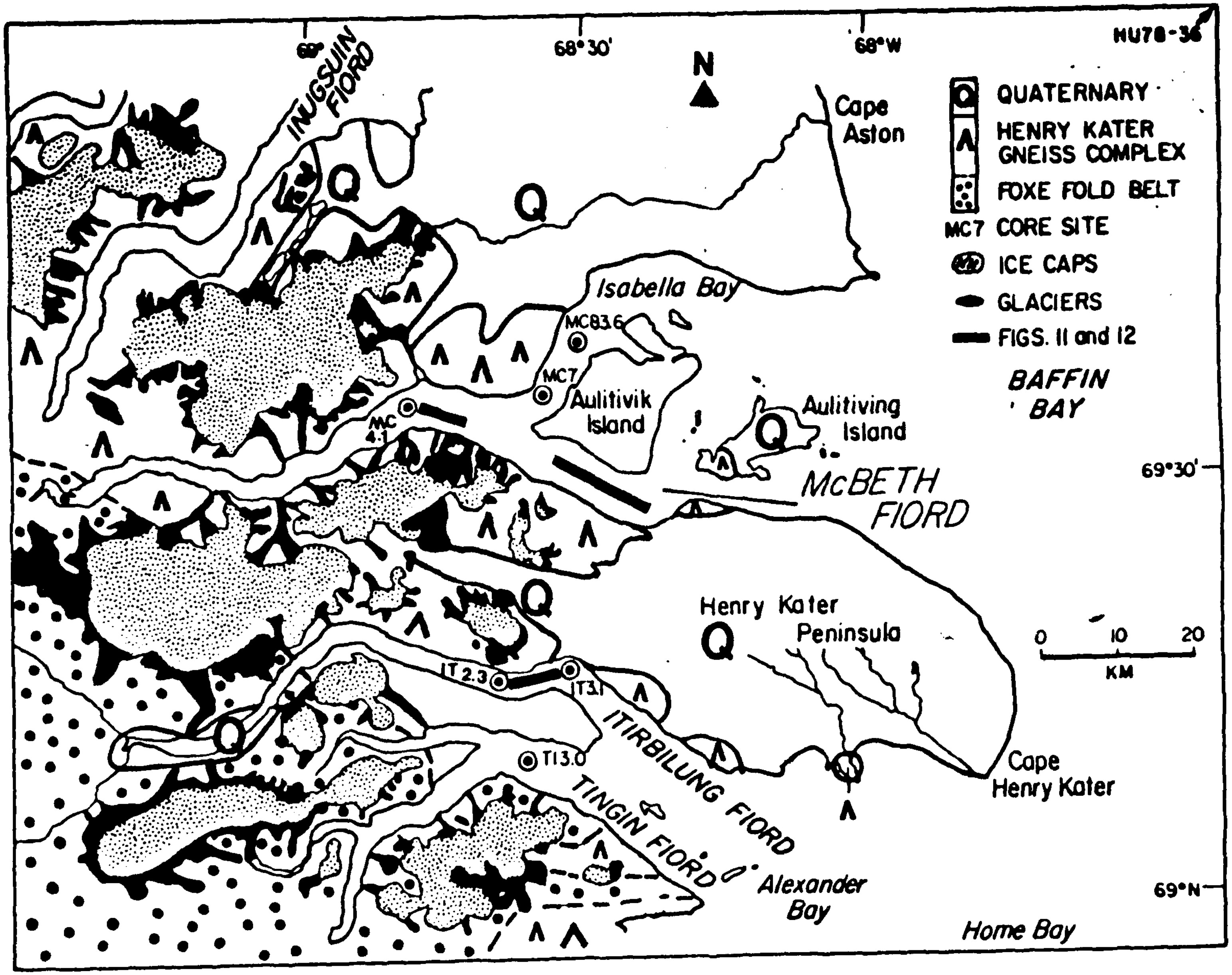

ACCUMULATION LAST 8ka.
10,000 KG/M2
5,000 KG/M2
KEY
SAND 15 %
SILT 45 %
CLAY 40 %
HU77-159
HU77-156
HU78-37
HU82-TI3
HU75-58
HU77-CL5
HU78-24
FIORDS
SHELF
DEEP SEA

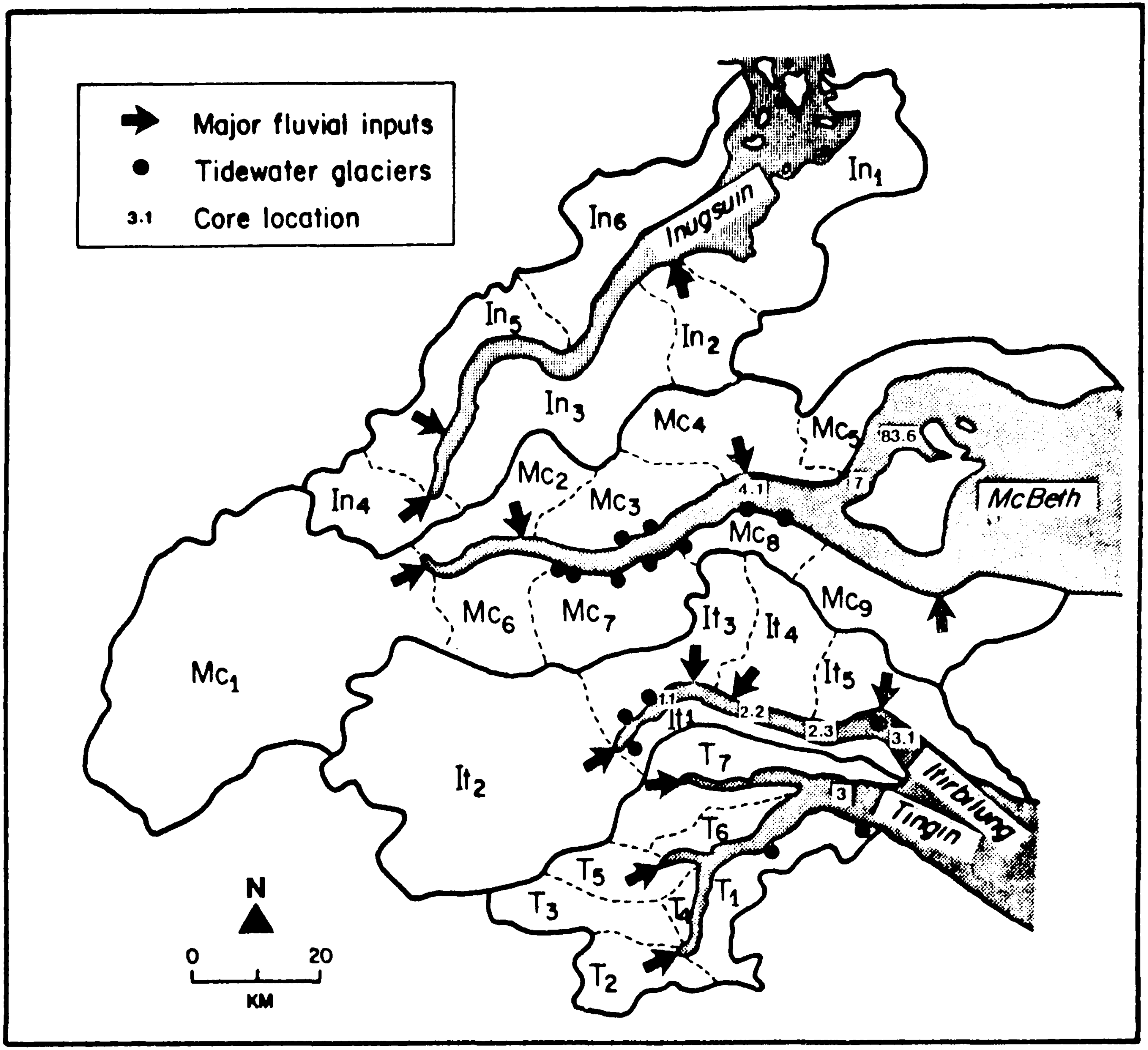


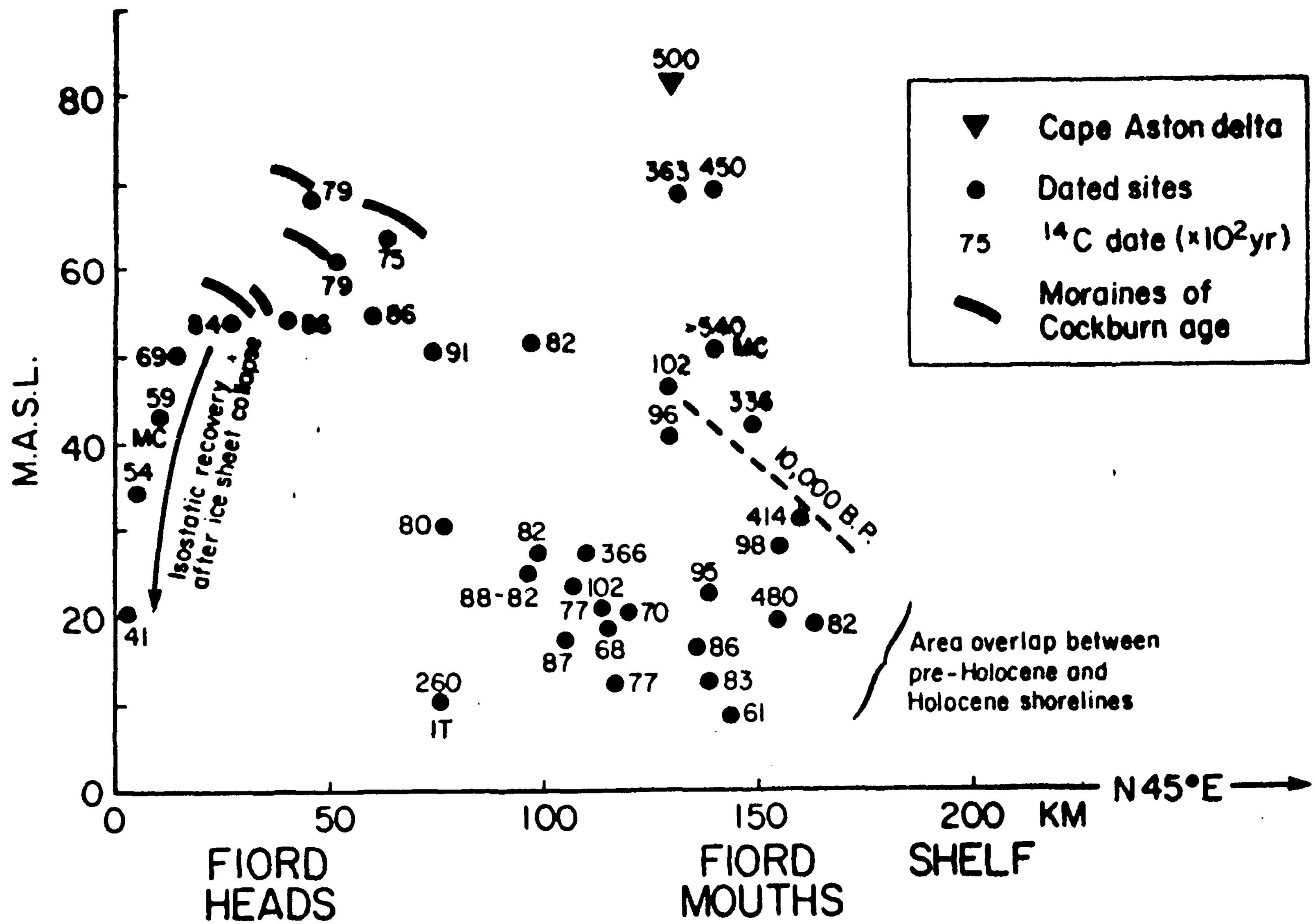
Fiord
10,000
(3)
Shelf
(4)
kg/m² 8km
1,000
700
500
300
200
Deep Sea
(3)
0
Fiord
Head
50
Shelf
100
Deep Sea
250
DISTANCE (km)


HU78-36
69°
68°30'
68°W
69°30'
69°N
N
INUGSUIN FIORD
Cape Aston
Cape Raper
Isabella Bay
MC83.6
MC7
Aulitivik Island
Aulitiving Island
MC 4.1
McBETH FIORD
MC2.0
MC2.1
BAFFIN BAY
Henry Kater Peninsula
ITIRBILUNG FIORD
TINGIN FIORD
IT1.1
IT2.2
IT2.3
IT3.1
TI3.0
Alexander Bay
Home Bay
Cape Henry Kater
0 10 20
KM
^{14}C, ka
MC 4.1 CORE SITE
ICE CAPS
GLACIERS
7.8
6.1
54
41
8.2
7.5
4.8
8.3
52
35
33
9.1
8.2
(25.8)
9.8
38
8.7
8.7

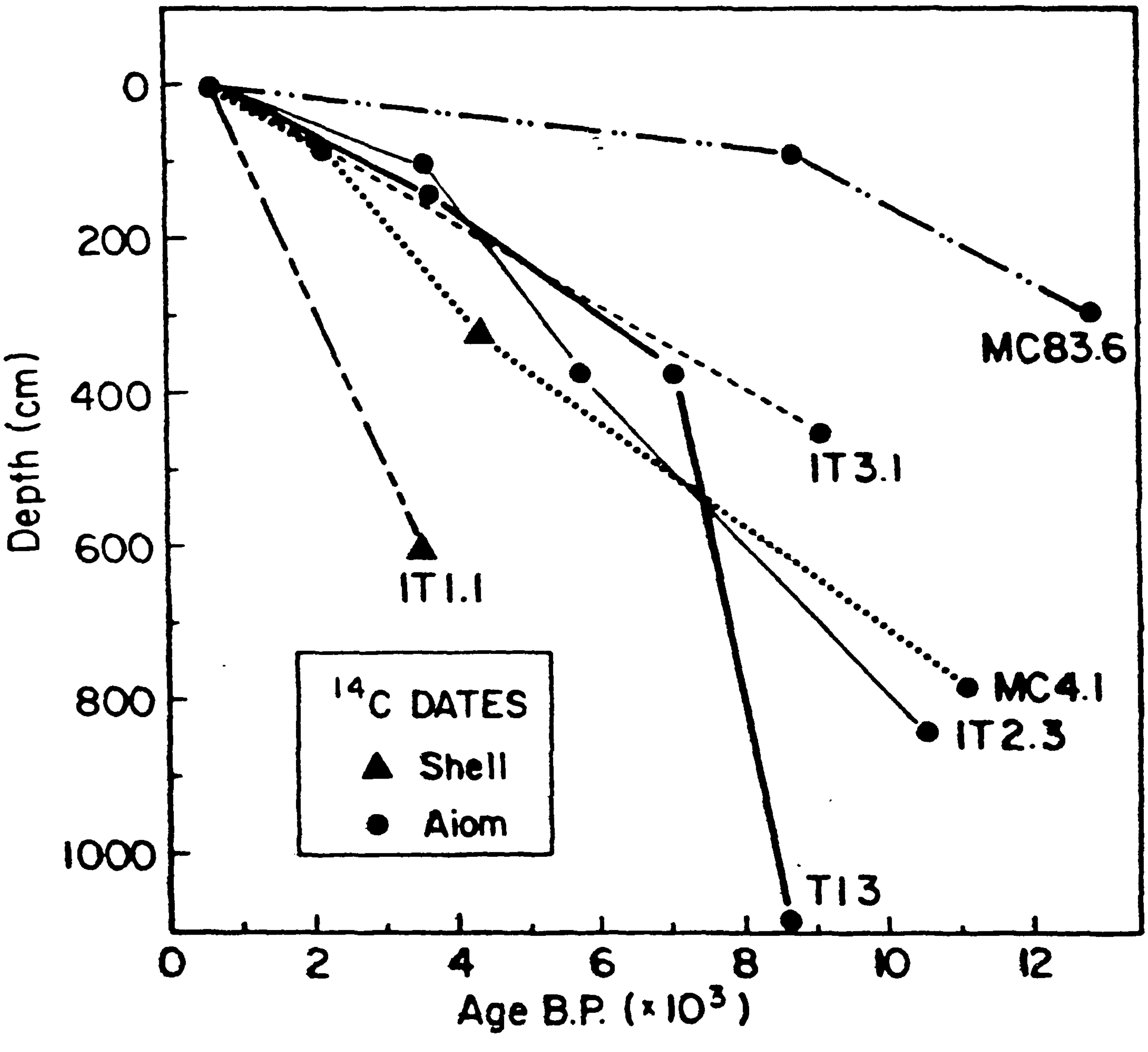

1
sea level
fiord sediment
2
sea level
H_2O?
3
sea level
outlet glacier
Glacial Foreland

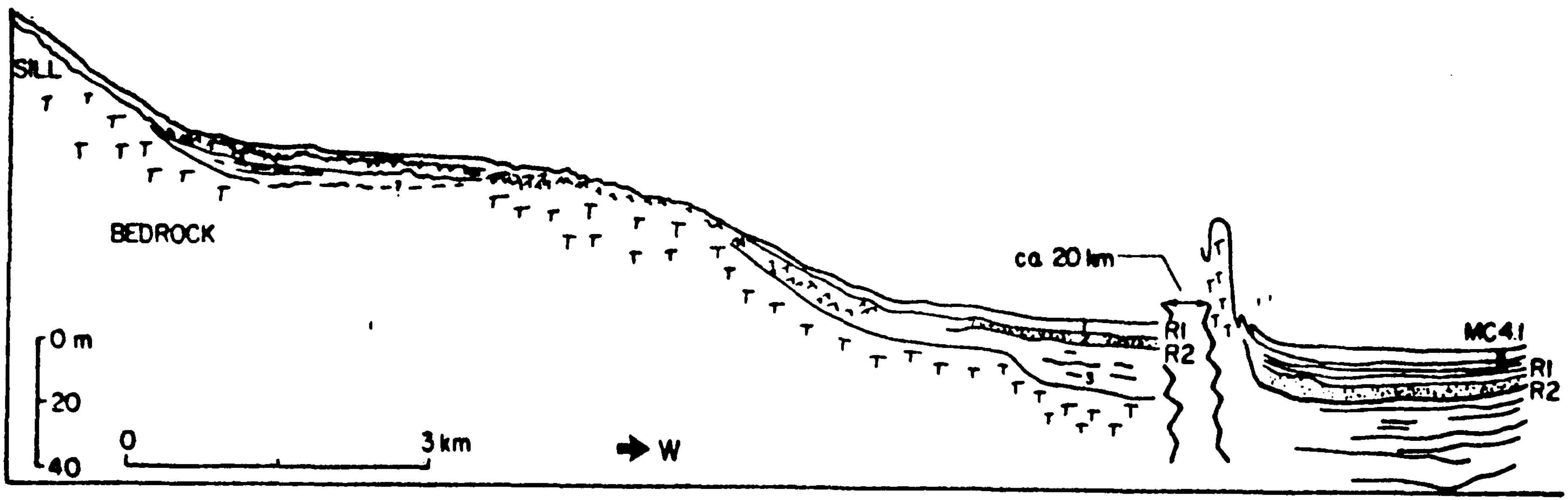

HU78-36
69°
68°30'
68°W
N
QUATERNARY
HENRY KATER GNEISS COMPLEX
FOXE FOLD BELT
MC7 CORE SITE
ICE CAPS
GLACIERS
FIGS. II and 12
BAFFIN BAY
INUGSUIN FIORD
Cape Aston
Isabella Bay
MC83.6
MC7
Aulitivik Island
Aulitiving Island
MC 4.1
McBETH FIORD
69°30'
Henry Kater Peninsula
0 10 20
KM
IT 2.3
IT3.1
T13.0
ITIRBILUNG FIORD
TINGIN FIORD
Cape Henry Kater
Alexander Bay
69°N
Home Bay

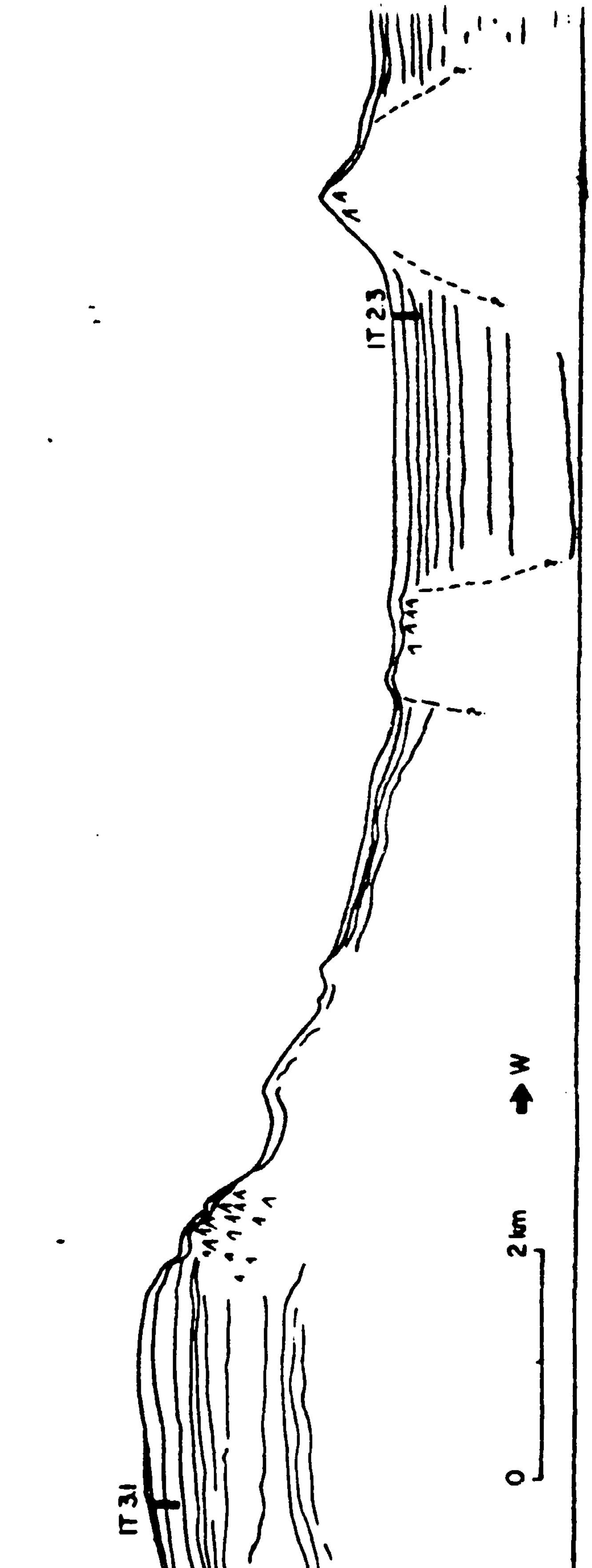

Major fluvial inputs
Tidewater glaciers
3.1 Core location
Inugsuin
McBeth
Itirbilung
Tingin
In1
In2
In3
In4
In5
In6
Mc1
Mc2
Mc3
Mc4
Mc5
Mc6
Mc7
Mc8
Mc9
It1
It2
It3
It4
It5
T1
T2
T3
T4
T5
T6
T7
83.6
7
4.1
1.1
2.2
2.3
3.1
3
N
0
20
KM

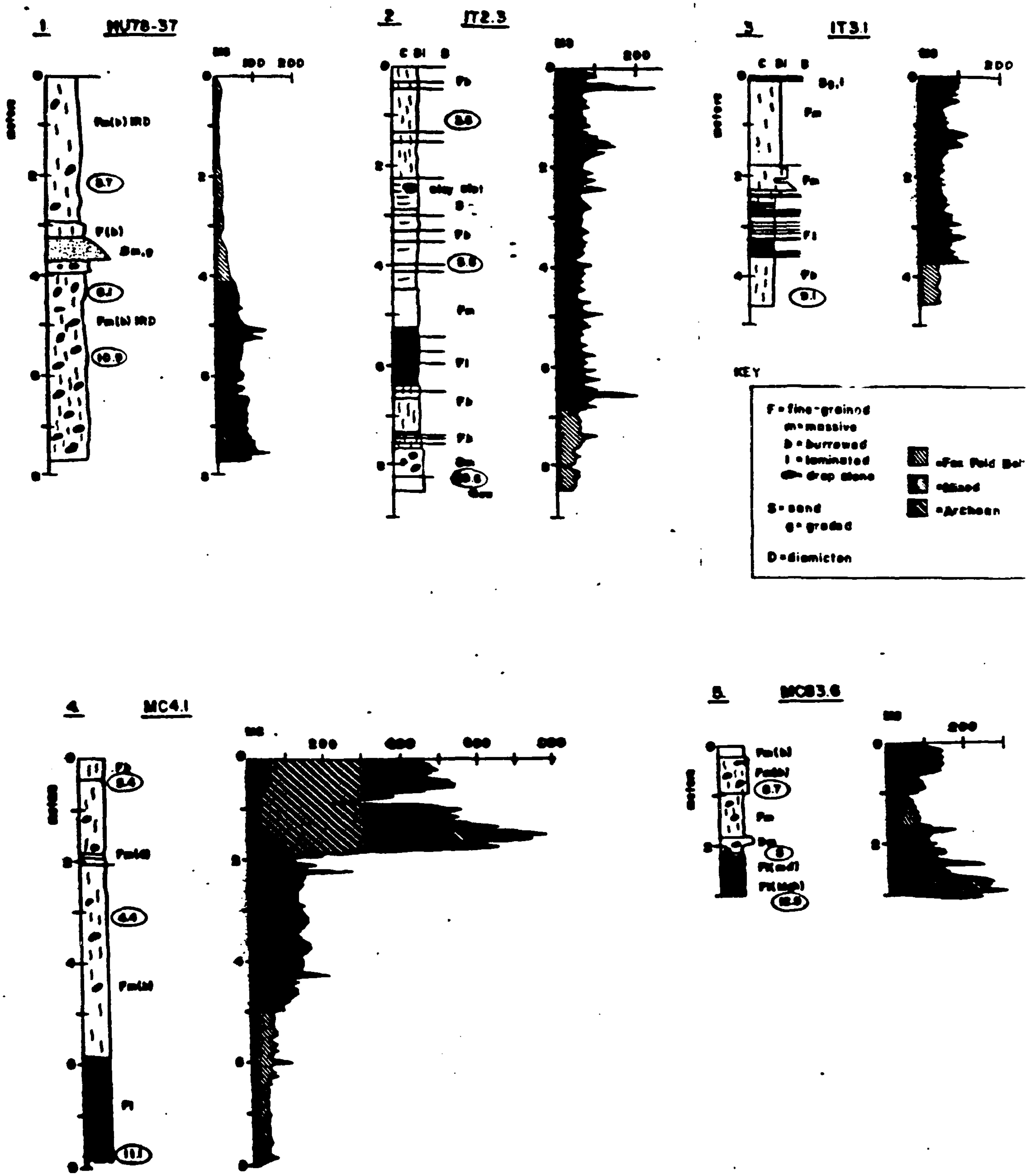


M.A.S.L.
Cape Aston delta
Dated sites
75 ^{14}C date (×10^{2}yr)
Moraines of Cockburn age
Isostatic recovery + after ice sheet collapse
10,000 B.P.
Area overlap between pre-Holocene and Holocene shorelines
KM
N45°E
FIORD HEADS
FIORD MOUTHS
SHELF

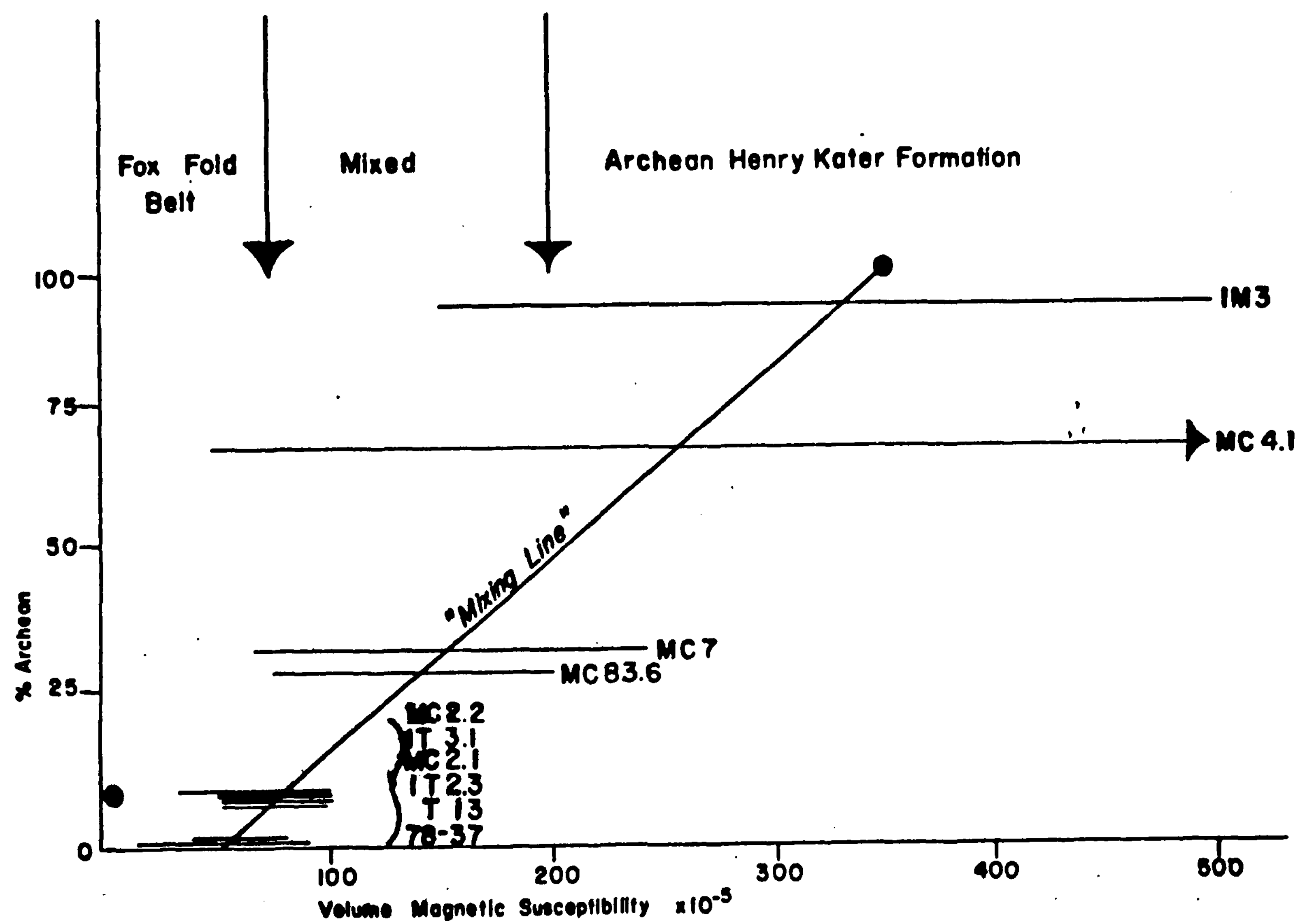

0
200
400
600
800
1000
Depth (cm)
0
2
4
6
8
10
12
Age B.P. (x 10³)
MC83.6
IT3.1
IT1.1
MC4.1
IT2.3
T13
¹⁴C DATES
Shell
Aiom


SILL
BEDROCK
0 m
20
40
0
3 km
W
ca. 20 km
R1
R2
MC4.1
R1
R2


IT 31
IT 23
0m
20
40
0
2km
W



1
2
IT2.3
3
IT3.1
Fm(b) IRD
Fm
Fl
Fb
0
200
KEY
F = fine-grained
m = massive
b = burrowed
l = laminated
drop stone
S = sand
g = graded
D = diamicton
= Mixed
= Archean
4
MC4.1
0
200
400
600
800
5
MC83.6


Fox Fold Belt
Mixed
Archean Henry Kater Formation
IM3
MC 4.1
"Mixing Line"
MC7
MC83.6
MC2.2
IT 3.1
MC2.1
IT2.3
T 13
78-37
100
75
50
25
0
% Archean
100
200
300
400
500
Volume Magnetic Susceptibility x10-5